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MEMORANDUM

STATIC STABILITY INVESTIGATION OF

SUPERSONIC-IMPACT BALLISTIC REENTRY SHAPES AT

MACH NUMBERS OF 2.55 AND 3.05

By John M. Swihart

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Langley Field, Va.

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

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MEMORANDUM 5-27-59L

STATIC STABILITY INVESTIGATION OF SUPERSONIC-IMPACT BALLISTIC REENTRY SHAPES AT MACH NUMBERS OF 2.55 AND 3.05*

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SUMMARY

An exploratory investigation of the static stability of several ballistic reentry shapes believed to be suitable for supersonic impact has been conducted in the Langley 9- by 12-inch blowdown tunnel at Mach numbers of 2.55 and 3.05. The angle-of-attack range was from -2° to 10° and the Reynolds numbers were 6.8×10^6 and 5.2×10^6 based on body length.

The results indicate that all of the models were stable and that one model with a 20° truncated-cone forebody, a cylindrical center body, an afterbody having a 10° flare, and a design impact Mach number of 1.90 was the most stable of those investigated. The center of pressure was located at about 50 percent of the body length for all models. Comparison of the results with Newtonian impact theory showed that the normal-force-curve slopes were about 20 percent greater than those predicted and the pitching-moment-curve slopes were about 30 to 40 percent lower than those predicted.

INTRODUCTION

Extensive research has been conducted on ballistic reentry bodies to insure their arrival at the target intact, and this research has led to families of subsonic-impact ballistic reentry shapes (for example, refs. 1 to 4). Studies of the dynamic oscillatory characteristics of these subsonic-impact shapes have indicated that most of the bodies are dynamically stable at supersonic speeds; however, the bodies become unstable as they decelerate through the transonic speed range. For

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these reasons and others, attention has turned to the design of supersonic-impact ballistic reentry bodies.

The purpose of this paper is to present results of an exploratory static stability investigation of several blunt-cone—cylinder—flare bodies to determine the feasibility of using these shapes for supersonic-impact ballistic reentry bodies. The investigation was made over an angle-of-attack range from -2° to 10° at Mach numbers of 2.55 and 3.05 and Reynolds numbers of 6.8×10^{6} and 5.2×10^{6} based on body length. Transition was fixed on the blunt nose at all times.

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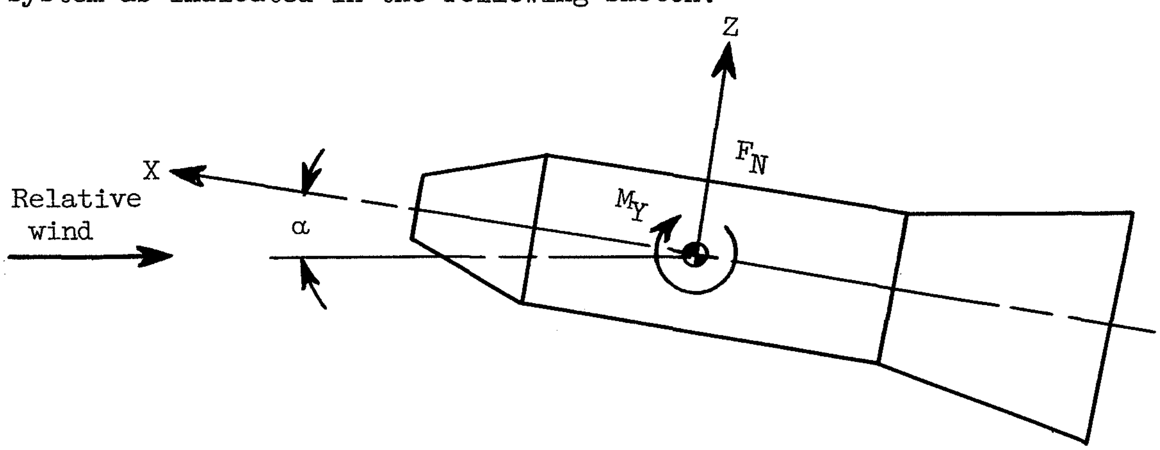
SYMBOLS

The coefficients presented in this paper are based on the body axis system as indicated in the following sketch:



A reference body cross-sectional area, $\pi d^2/4$

C_N normal-force coefficient, F_N/qA

C_m pitching-moment coefficient $\left(\text{measured at } 0.398\frac{x}{l} \text{ for models I, II, and III and at } 0.422\frac{x}{l} \text{ for model IV}\right)$, M_Y/qAd

C_{N_α} normal-force-curve slope, $\partial C_N/\partial\alpha$, per deg

C_{m_α} pitching-moment-curve slope, $\partial C_m/\partial\alpha$, per deg

d reference diameter, 1.741 inches

F_N normal force

[redacted]

l model length

M Mach number

M_Y pitching moment

q free-stream dynamic pressure

x_{cp}/l center-of-pressure location, fraction of body length

L375 x longitudinal distance rearward of body nose, in.

α angle of attack, deg

APPARATUS AND METHODS

Models

Sketches of the four models used in the investigation are presented in figure 1. Photographs of the four models and model I mounted on the tunnel sting-support system are shown as figure 2. Models I, II, and III have the same truncated-cone nose or forebody but have different cylindrical-center-body lengths and afterbody angles of flare. These three models have design impact Mach numbers of 2.35, 2.30, and 1.90 if assumed initial reentry angles of 37° and drag coefficients obtained by means of Newtonian theory (reduced by 20 percent) of 0.509, 0.520, and 0.576, respectively, are used. Model IV differs from model III only in the length of the nose; consequently, model IV has a reduced diameter of flat face and would be expected to have a lower drag coefficient. Calculations by use of Newtonian theory (also reduced by 20 percent) indicate a drag coefficient of 0.437 for model IV and this drag coefficient resulted in a calculated impact Mach number of 3.1.

All models were constructed of aluminum and all had transition fixed at the 0.75 radius of the front face. The grain size necessary to cause transition was calculated by the use of references 5 and 6 and was found to be No. 180 carborundum which ranged from 0.003 to 0.005 inch in diameter.

Test and Measurements

The investigation was conducted in the Langley 9- by 12-inch blowdown tunnel at Mach numbers of 2.55 and 3.05 and at a stagnation pressure of 50 pounds per square inch absolute. The two Mach numbers were obtained by using interchangeable nozzle blocks. The Reynolds number

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based on body length was approximately 6.8×10^6 at $M = 2.55$ and approximately 5.2×10^6 at $M = 3.05$. The sting-support system was attached to a plate in the tunnel floor which rotated to permit angle-of-attack variation; the plate and the sting-support system are shown in figure 2(b). The angle-of-attack range was from -2° to 10° at $M = 2.55$ and from -2° to the highest angle less than 10° attainable at $M = 3.05$ before unsteady flow occurred. Unsteady flow was observed as a violent shaking of the model, even though the flow about the body remained supersonic.

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The models were mounted on a 5-component strain-gage balance which did not have an axial-force beam. The forces and moments were determined from the output of self-balancing potentiometers which were recorded on pen-type strip charts. The angle of attack was corrected for sting and balance deflections under load and for a tunnel downflow angle of 0.5° at a Mach number of 3.05.

The estimated maximum errors of the quantities presented in this paper are as follows:

M	± 0.02
C_N	± 0.02
C_m	± 0.01
α, deg	± 0.10

RESULTS AND DISCUSSION

Basic Data

The effect of angle of attack on normal-force coefficient and on pitching-moment coefficient for all models at the two test Mach numbers is shown in figure 3. The normal-force coefficients are fairly linear at the low angles of attack and become nonlinear, as would be expected, at angles of attack above about 6°. Model IV, which had the lowest calculated drag coefficient, was the only model which could be operated above an angle of attack of 4° at $M = 3.05$. In figure 3(d) the flagged symbols indicate data obtained with the transition grain removed from model IV. These is no apparent effect of fixing transition on either the normal-force coefficient or pitching-moment coefficient for model IV at $M = 3.05$ and corresponding Reynolds number at angles of attack up to 10°.

The pitching-moment coefficients for all models are not linear at $M = 2.55$ even at angles of attack near 0°; this is an indication that the center of pressure is shifting with angle of attack. In general,

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the pitching-moment data at $M = 3.05$ appear to be more linear than at $M = 2.55$. The pitching-moment-coefficient data for model IV at $M = 3.05$ indicate increasing stability at the higher angles of attack, probably the result of increased lift effectiveness of the afterbody having a 10° flare. It is possible that the other models might also have indicated increasing stability if they could have been operated at the higher angles of attack at $M = 3.05$.

Slope Parameters

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The normal-force-curve slope $C_{N_{\alpha}}$ and the pitching-moment-curve slope $C_{m_{\alpha}}$ of all the models are compared with Newtonian theory at the two test Mach numbers in figure 4. The data indicate that all the models are stable and that model III is the most stable of the four investigated. The 10° flare angle provides the most stability of the three flare angles investigated, and the reason that model IV is slightly less stable than model III is probably the result of the increased nose length. Comparison of the experimental slope parameters with those calculated by use of Newtonian theory (equations presented in ref. 1) indicates that in this speed range ($M = 2.55$ to $M = 3.05$) the calculated normal-force-curve slope $C_{N_{\alpha}}$ is about 20 percent lower and the calculated pitching-moment-curve slope $C_{m_{\alpha}}$ is about 30 to 40 percent higher. It probably should not be expected that Newtonian impact theory would give good results in this speed range, inasmuch as the flow is not approaching hypersonic values. The addition of centrifugal effects by a modification to Newton's impact theory might yield more accurate estimates, particularly for blunt bodies at these Mach numbers (ref. 7).

Center-of-Pressure Location

The location of the center of pressure in terms of body length is shown in figure 5 for all models at the two test Mach numbers, and the data indicate that the center of pressure is located at about 50 percent of the body length for all models. Model IV has a center-of-pressure location just slightly rearward of that of model III; however, the lower pitching-moment-curve slope $C_{m_{\alpha}}$ for model IV (probably the result of nose length ahead of center of gravity) still gives it less stability than that of model III in spite of its more rearward center-of-pressure location.

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CONCLUDING REMARKS

An investigation of the static stability of ballistic reentry shapes believed to be suitable for supersonic impact has been made at Mach numbers of 2.55 and 3.05. The results indicate that a shape with a blunt 20° conical forebody, a cylindrical center section, an afterbody having a 10° flare, and a design impact Mach number of 1.90 was the most stable of those investigated. The experimental normal-force-curve slopes were about 20 percent greater than those predicted by Newtonian impact theory,
and the pitching-moment-curve slopes were about 30 to 40 percent lower L
than those predicted by the theory. The pitching-moment-coefficient 3
curves were nonlinear at both test Mach numbers, being slightly more 7
nonlinear at a Mach number of 2.55. The center of pressure was generally 5
located at about 50 percent of the body length for all models.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., March 9, 1959.

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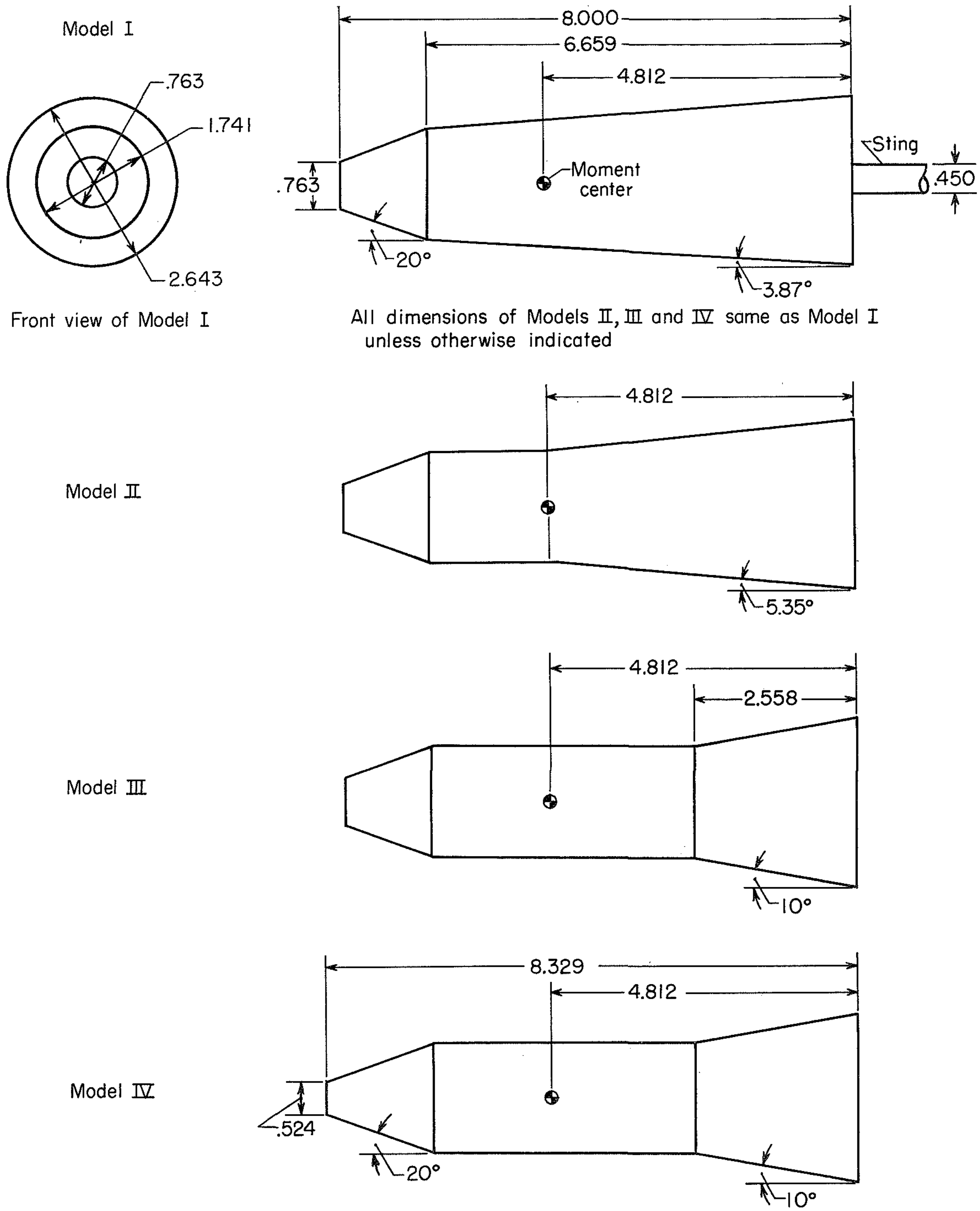

Figure 1.- Model geometry. All dimensions are in inches.

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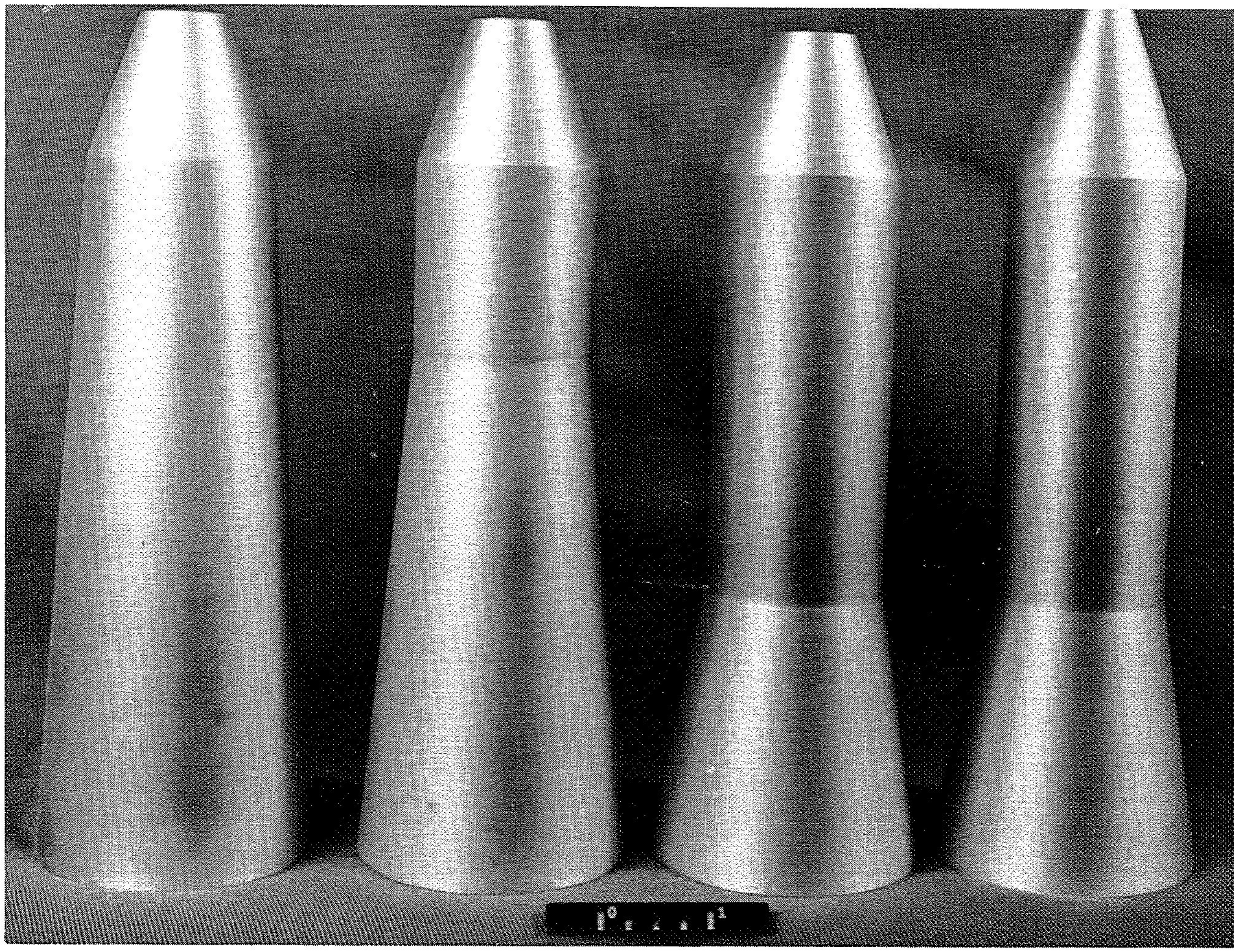

(a) Models I, II, III, and IV. L-58-3176

Figure 2.- Models used in investigation.

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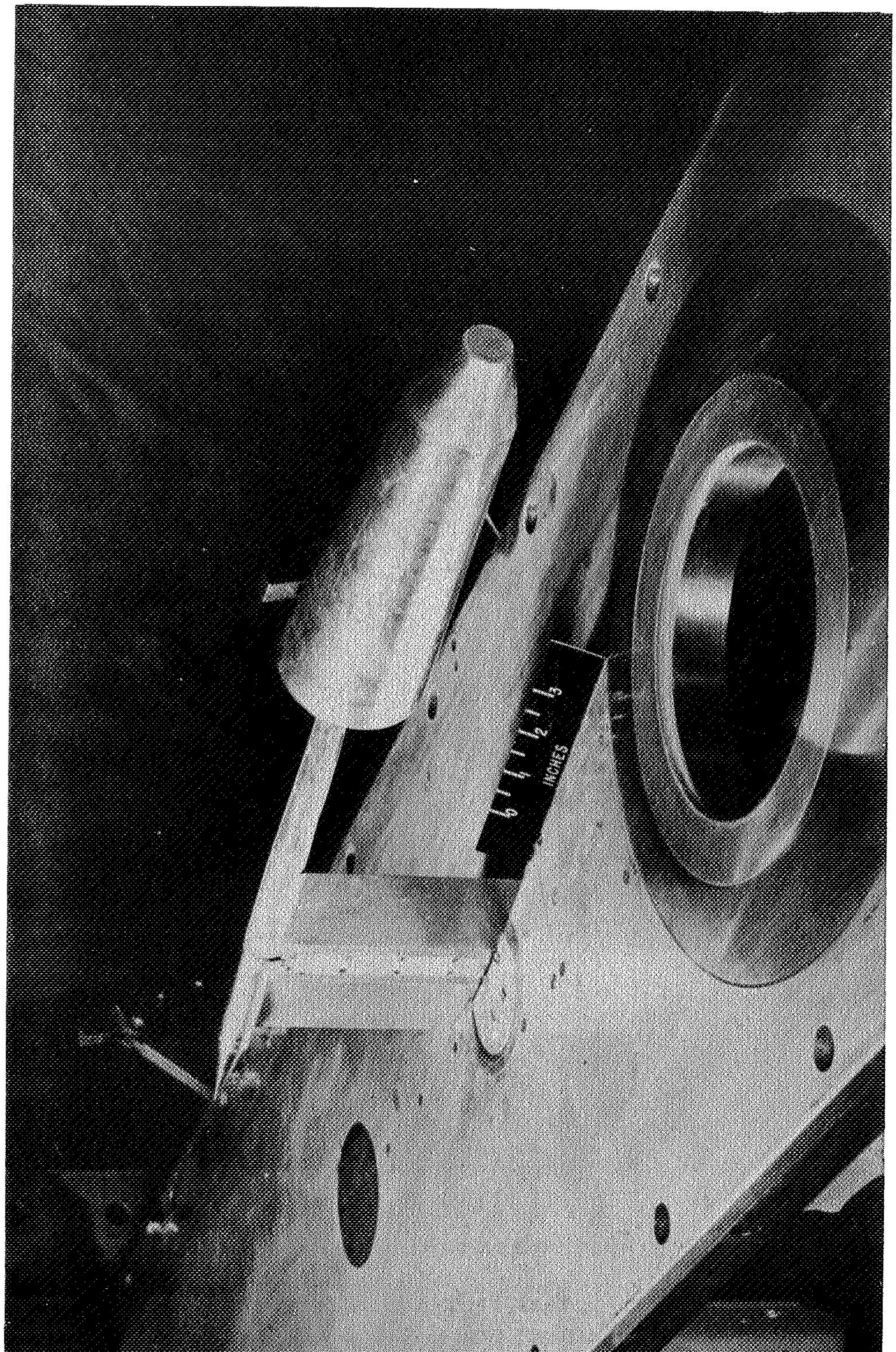

(b) Model I mounted on sting support. L-58-3305

Figure 2.- Concluded.

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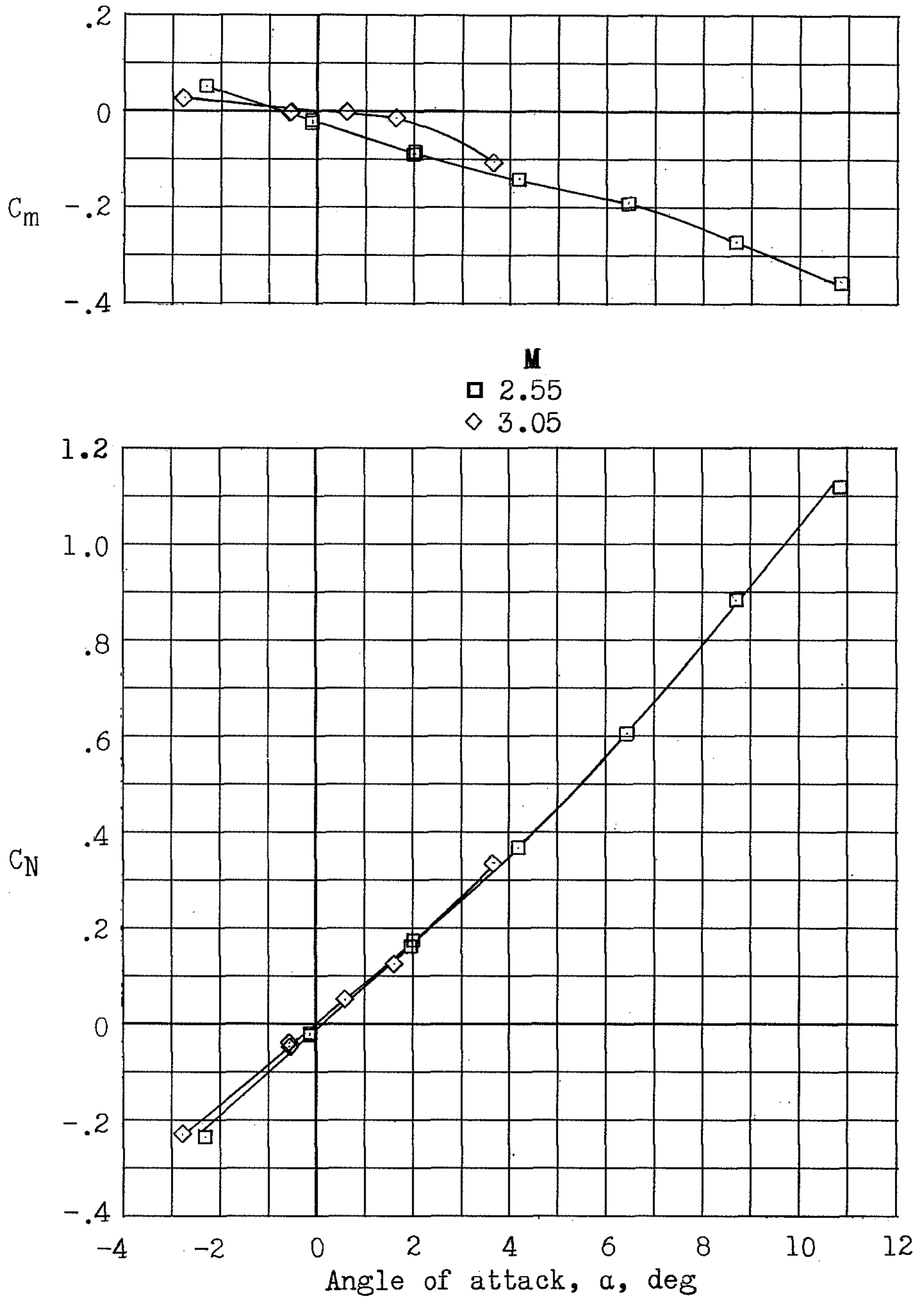

(a) Model I.

Figure 3.- Effect of angle of attack on normal-force coefficient and pitching-moment coefficient at the two test Mach numbers.

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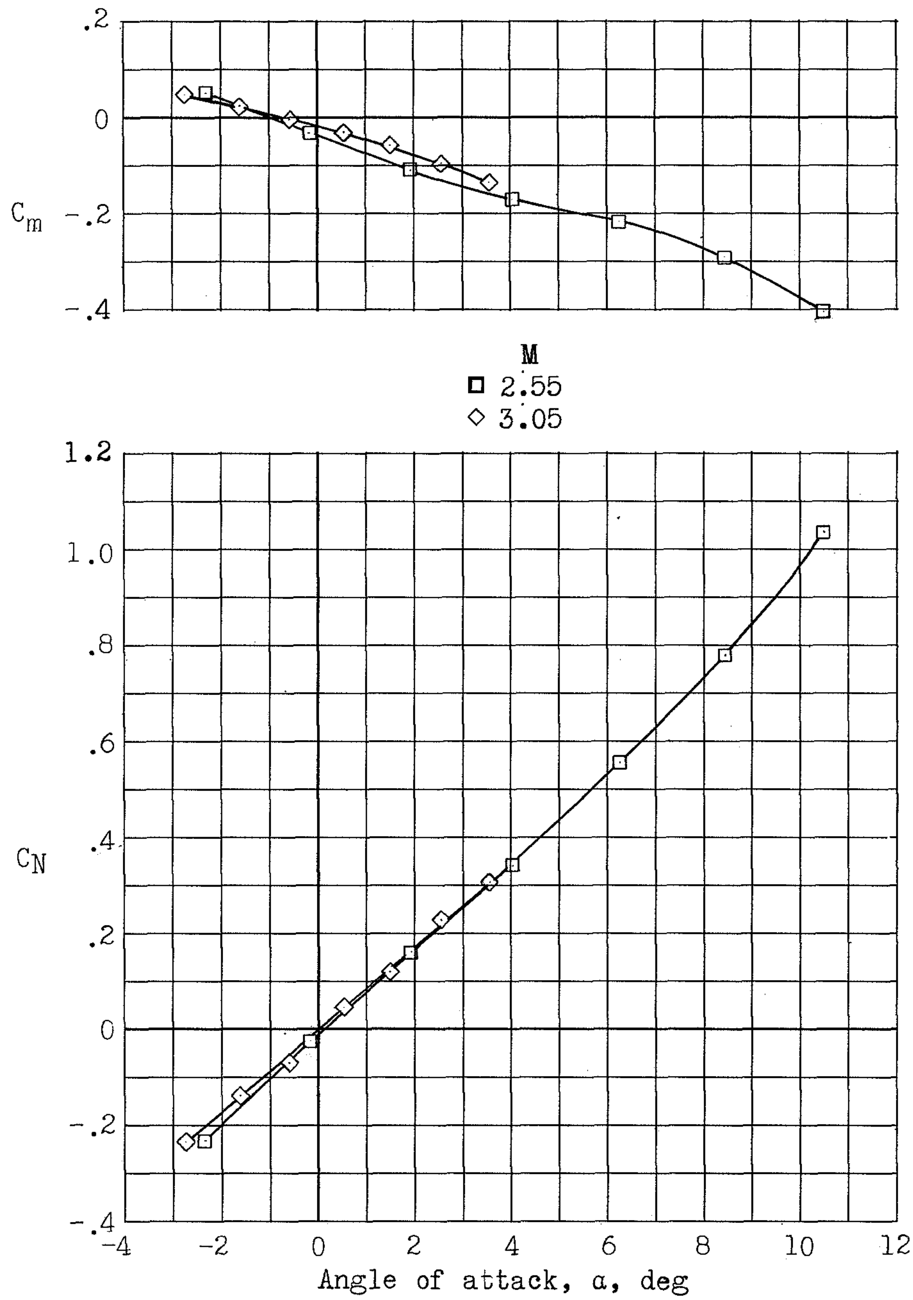

(b) Model II.

Figure 3.- Continued.

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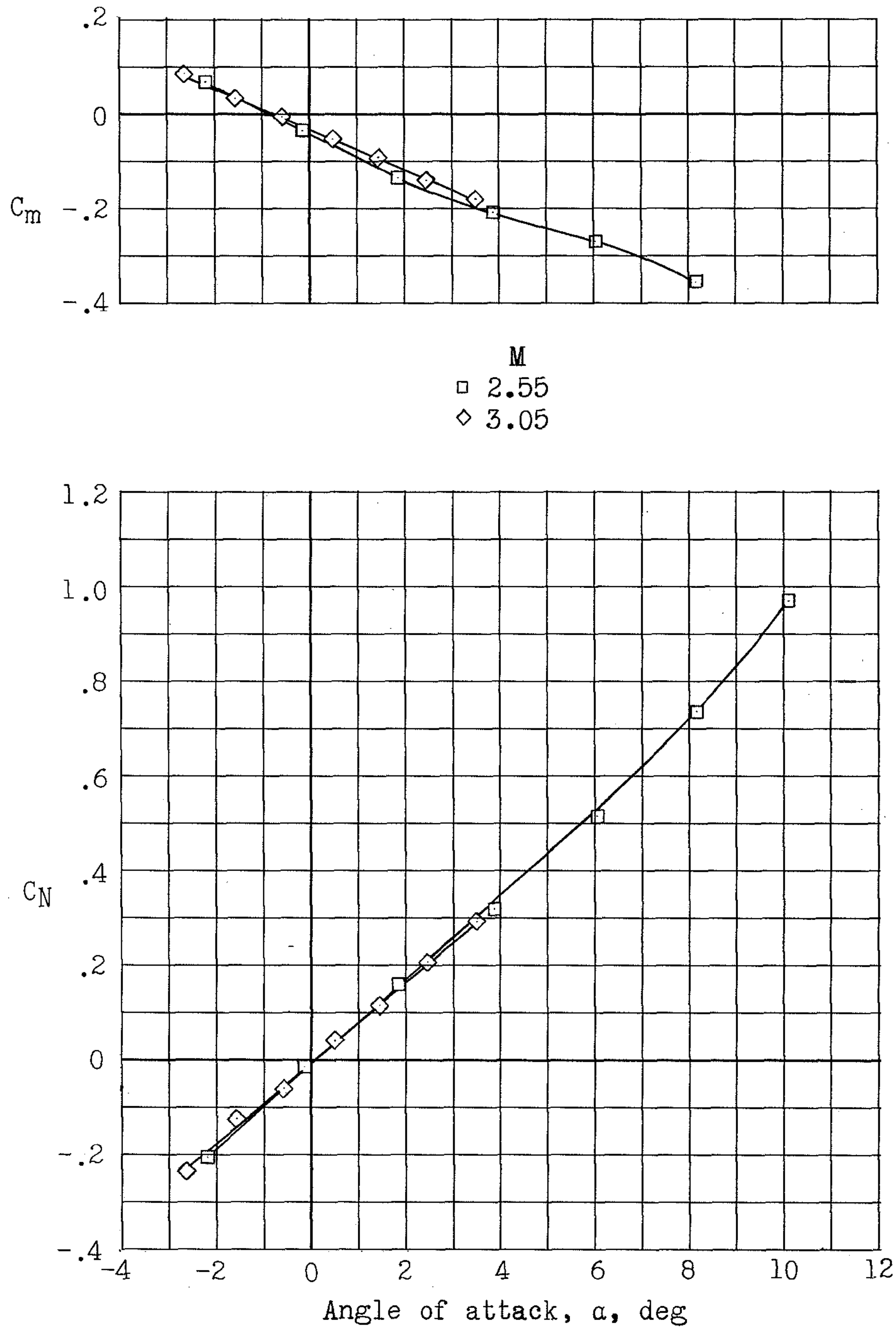

(c) Model III.

Figure 3.- Continued.

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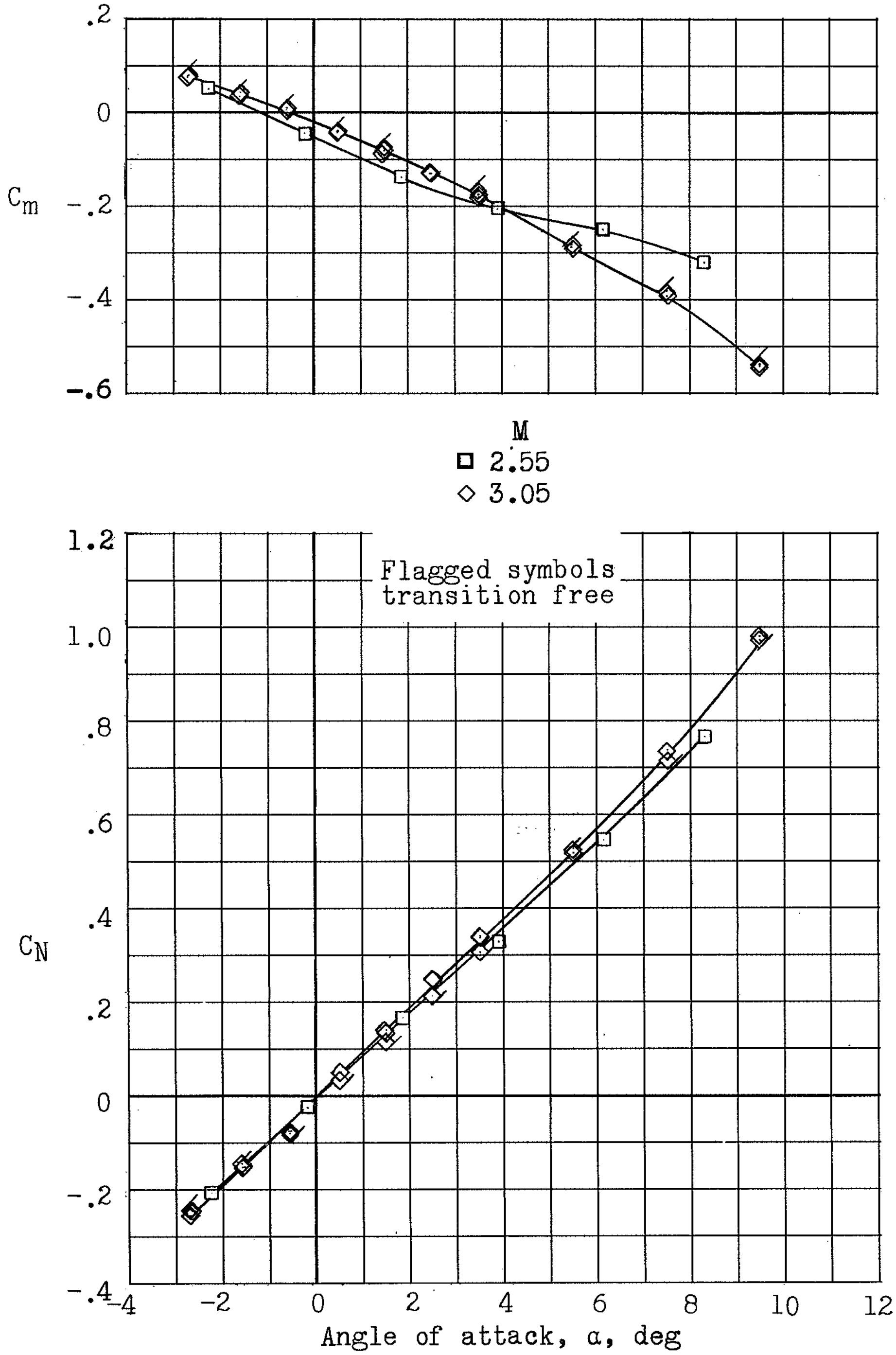

(d) Model IV.

Figure 3.- Concluded.

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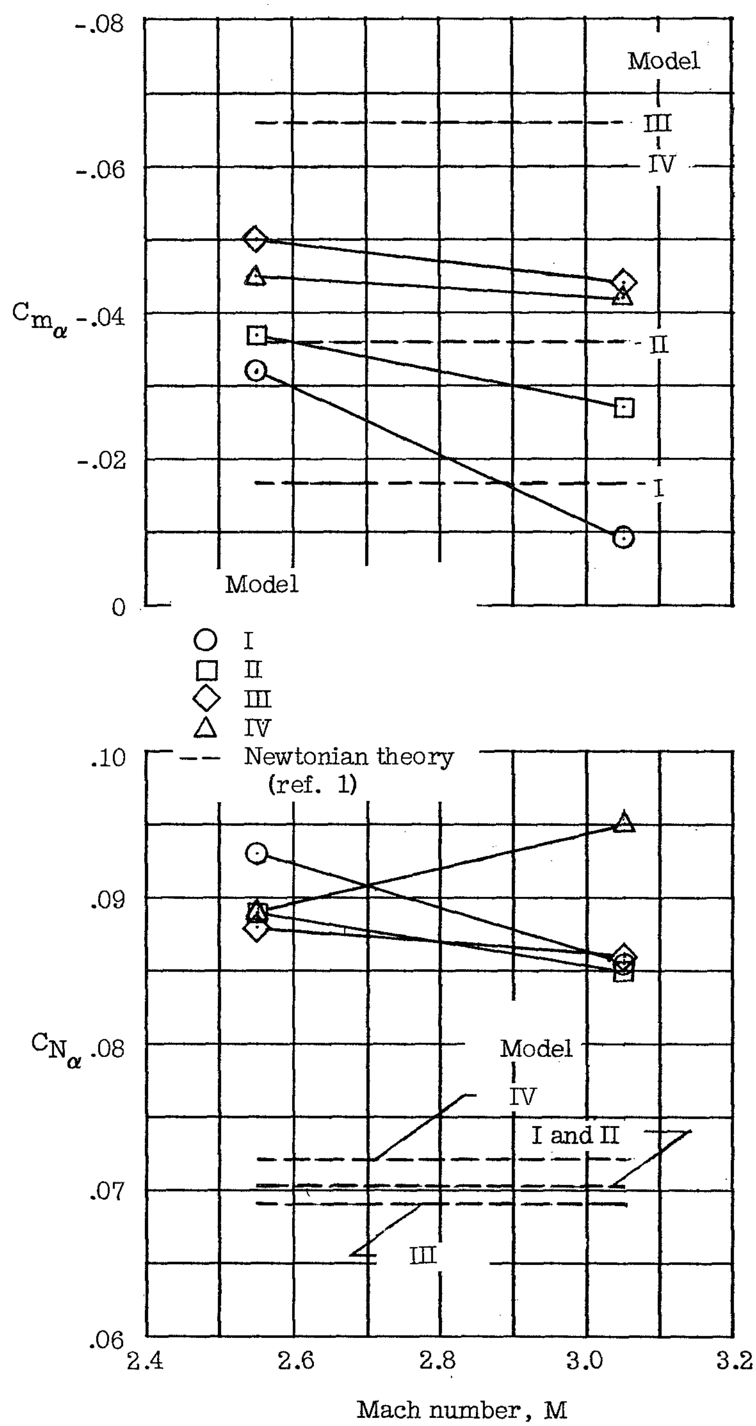

Figure 4.- Effect of Mach number on C_{N_α} and C_{m_α} and a comparison with Newtonian theory.

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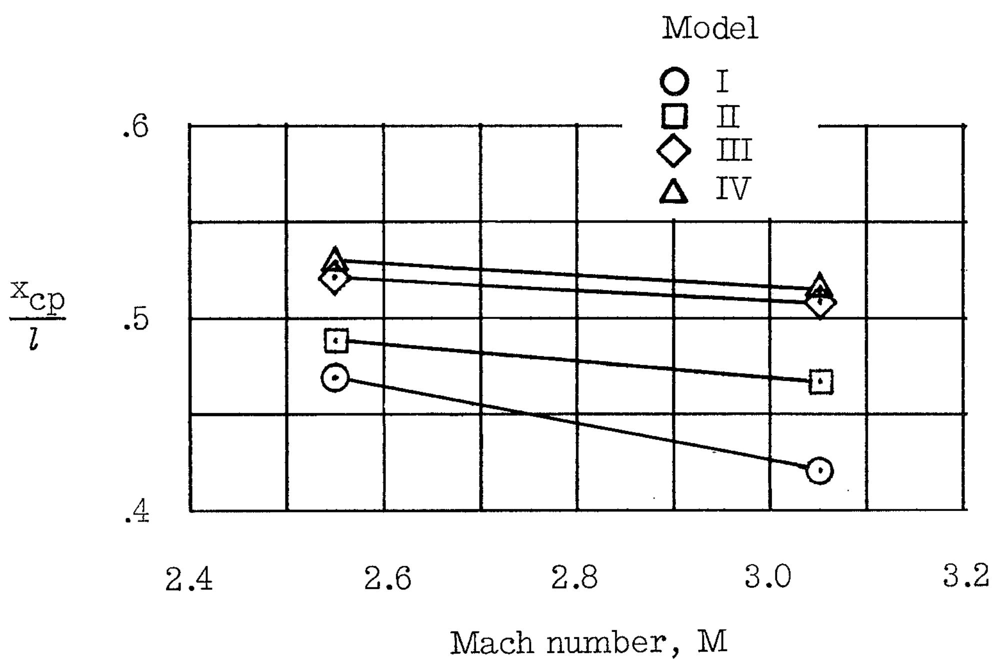

Figure 5.- Location of center of pressure for all models at the two test Mach numbers.

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